

**A Method and Apparatus to Estimate Burn-In Time by
Measurement of Scribe-Line Devices, With Stacking Devices,
And With Common Pads**

Background of the Invention

Field of the Invention

[0001] This invention generally relates methods and structures for evaluating and assuring reliability of electronic components. More particularly this invention relates to testing methods and structures to evaluate and minimize burn-in testing of semiconductor wafers onto which integrated circuits are formed.

Description of Related Art

[0002] As integrated circuit densities and circuit performance has increased, the equipment necessary to evaluate and assure the reliability and functionality of the integrated circuits has become more complex and consequently more expensive. It is well known in the art and shown in Fig. 1 that the hazard rate or probability of failure of integrated circuits follows the commonly referred to "bathtub" curve 10. During evaluation of product requirements, the target hazard rate 5 of the integrated circuit is established. Whenever the hazard rate 10 of the integrated circuit exceeds the target hazard rate 5, the integrated circuit is not deemed

sufficiently reliable for its intended application. The failures that occur in the early life period **15** of operation of the integrated circuit are referred to as infant mortality.

5 [0003] To predict the actual hazard rate **10** of the integrated circuits, wafer level reliability experiments are performed to detect the failure mechanisms and their impact on the actual hazard rate **10**. The predicted hazard rate **20** does not detect lot-to-lot variations that impact the hazard rate **10** nor does it detect and unique variations **25** in the actual hazard rate **10**. The reliability experiments facilitate determination of a burn-in schedule that is to eliminate the infant mortality failures from the integrated circuits. However, the lot-to-lot variations may mean that the burn-in schedule may significantly shorten the useful duration **30** of the integrated circuits and in the extreme, cause the integrated circuit to enter the wear-out period **35** earlier than expected.

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15 [0004] The reliability evaluation testing and the burn-in testing utilize unique integrated circuit structures to evaluate the results of stress upon the integrated circuit that can cause failure. Typically the structures include, capacitor dielectric film evaluation devices, gate oxide integrity devices, polycrystalline silicon heating devices, contact metallurgy evaluation chains, interlayer via chains, MOS evaluation devices, plasma etching antenna effect patterns, metal electromigration structures, memory cell array, and specially designed circuit block structures. These

structures examine the susceptibility of the integrated circuit failures due to such failure mechanisms as pin holes in insulating material such as gate oxides and other inter-level insulating materials, corrosion of metal layers in the presence of moisture, electromigration of the metal layers, etc.

[0005] During the technology reliability evaluation the test structures are formed as test sites on an integrated circuit die. An integrated circuit die typically contains one unique test structure to allow creation of a sufficiently large sample size to detect long term or low-level failure phenomena. However, during wafer-level test, the actual functional integrated circuits occupy, as shown in Fig. 2, the die 50 and any test structures or test sites are placed in the kerf or scribe lines 55 area between each integrated circuit die 50. Since the scribe line area 55 is relatively small, the test structure must occupy a relatively small area. This forces a relatively small sample size for evaluation of particular failure mechanisms that have low defect density. Thus, this small sample size does not allow sufficient sensitivity to indicate the defect density prior to burn-in. This forces the burn-in to be longer than necessary to assure that the infant mortality failures are screened from the production lot. For instance, evaluation of the characteristics of individual MOS transistors requires four bonding pads for each device. The bonding pads are relatively large and consume significantly more area than the MOS transistors. Therefore placing test structures for the individual transistors

in the scribe lines **55** limits the number of transistors available for evaluation.

[0006] U.S. Patent 6,157,046 (Corbett et al.) describes a semiconductor test chip. The semiconductor test chip includes structures for evaluating bond pad design effects and damage (cratering) effects, scribe lane width effects, thermal impedance effects of the die, ion mobility evaluation capabilities, and flip chip on board application test capabilities.

[0007] U.S. Patent 6,064,213 (Khandros et al.) describes a wafer-level burn-in and test system that allows a wafer containing integrated circuits to be stressed and evaluated to conduct burn-in of the wafer to assure correct functioning of the wafer.

[0008] U.S. Patent 6,246,075 (Su et al.) describes an ensemble of test structures for monitoring gate oxide defect densities and plasma antenna effects. The structures maybe included as a test site on a wafer containing integrated circuits or as test structures for reliability evaluation of an integrated circuit process.

[0009] U.S. Patent 5,981,971 (Miyakawa) describes a semiconductor ROM wafer test structure, and IC card. The circuit structure such as the ROM is tested via a test pad formed on a scribe line. Since the test pad is formed on the scribe line, when the die containing the ROM has been cut

off and separated from other chips along the scribe lines, the test pads are destroyed preventing future testing of the ROM.

[0010] U.S. Patent 5,946,248 (Chien et al.) and U.S. Patent 5,995,428 (Chien et al.) describe methods where a wafer containing memory devices, such as a DRAM (dynamic random access memory) are subjected to a burn-in operation of the memory device. As described in Miyakawa, pads are formed in the scribe lines. These pads are used to transfer an externally generated burn-in enable signal and a DC bias voltage to each memory device. Since the pads for burn-in wiring are formed in the scribe lines, they will not take additional space on the die where each memory device is formed.

[0011] U.S. Patent 5,057,441 (Gutt et al.) describes a method for reliability testing integrated circuit metal films using a noise measurement technique. In one embodiment, a film portion to be tested is incorporated in a Wheatstone bridge circuit within a test site. A relatively large direct current is passed through the film to stimulate $1/f^2$ noise. A relatively small alternating current is concurrently passed through the film. The bridge imbalance signal at the ac frequency is amplified and demodulated by a phase-locked amplifier, and is then frequency analyzed. The film is evaluated by comparing the resulting noise power spectrum with predetermined standards.

[0012] U.S. Patent 5,808,947 (McClure) teaches an integrated circuit that includes both a wafer test-mode path that is operable to carry a wafer test-mode signal and a wafer power-supply path that is operable to carry a wafer power-supply signal. The integrated circuit includes functional circuitry that supports normal and wafer-test modes of operation and that is coupled to the wafer test-mode path before the die is detached from the wafer. The functional circuitry is tested for operation when placed in the wafer test mode and functions normally when removed from the wafer test mode. The circuitry for the wafer test-mode path and the wafer power-supply path are located in the scribe line region of the wafer.

[0013] U.S. Patent 6,233,184 (Barth et al.) describes structures for wafer level test and burn-in. The structures include a state machine or programmable test engines located on the wafer in the area not including the functional circuitry. Each test engine requires fewer than ten connections and each test engine can be connected to multiple integrated circuit die. Thus, the number of pads of the wafer that must be connected for test is substantially reduced while a large degree of parallel testing is still provided. Connections to the wafer and between test engines and chips are provided along a membrane attached to the wafer. Membrane connectors can be formed or opened after the membrane is connected to the wafer so shorted chips can be disconnected.

Summary of the Invention

[0014] An object of this invention is to provide a method for estimating burn-in time for integrated circuit die on a wafer.

[0015] Another object of this invention is to provide a reliability testing structure to permit improved estimation of burn-in time for integrated circuit on a wafer.

[0016] Further, another object of this invention is to provide a reliability test structure placed in a scribe line area of a wafer to permit improved estimation of burn-in time for integrated circuits on a wafer.

[0017] Still further, another object of this invention is to provide multiple evaluation test devices within a reliability testing structure to permit improved estimation of burn-in time for integrated circuits on a wafer.

[0018] To accomplish at least one of these objects and other objects, a method for estimating burn-in time for integrated circuits begins by providing a semiconductor substrate onto which a plurality of reliability testing structures are formed.

[0019] Each reliability testing structure has a plurality of evaluation device structures formed on the substrate. Groups of the evaluation device structures are stacked on the surface of the substrate. The device structures are created to permit evaluation of one of a plurality of failure

mechanisms of the integrated circuit. The evaluation devices are such devices as capacitor dielectric film evaluation devices, gate oxide integrity devices, polycrystalline silicon heating devices, contact metallurgy evaluation chains, interlayer via chains, MOS evaluation devices, plasma etching antenna effect patterns, metal electromigration structures, memory cell array, and specially designed circuit block structures.

[0020] Each evaluation device structure is connected to a first forcing input pad and a first sensing output pad. The first forcing input pad provides a first forcing stimulus to at least one of the evaluation device structures to stress the evaluation device structure. The first sensing output pad is connected to sense a first response signal from at least one of the evaluation device structures.

[0021] A second forcing input pad and a second sensing output pad are connected through a selection circuit to at least one of the evaluation devices. The second forcing input pad provides a second forcing stimulus to at least one of the evaluation device structures to further stress the evaluation device structure. The second sensing pad senses a second response signal from the evaluation device structure.

[0022] The selection circuit is connected to select which of the evaluation devices are to receive the second stimulus and to transmit the second response. The selection circuit includes a plurality of transmission MOS devices. Each of the transmission MOS devices is connected between

the first stimulus input pad and one of the evaluation device structures. A decoder circuit is in communication with a gate terminal of each of the plurality of transmission MOS devices to activate the selected transmission MOS devices to selectively connect at least one of the evaluation device structures to the first stimulus input pad. A counter circuit is in communication with the decoder circuit to create from an increment signal an address code indicating which of the evaluation device structures are to be selected. The increment signal is applied to the decoder through a function control input pad. The increment signal stimulates the counter to increment and, thus, modify the address code to select which of the evaluation device structures are selected.

[0023] The counter circuit has an adder circuit, which sums a present address code with the select signal to generate the next address code. The adder circuit communicates with a first transmission gate to selectively transmit the next address code to a first buffer, which receives and retains the next address code. The first buffer is connected to communicate with a second transmission gate, which selectively transmits the next address code from the first buffer to a second buffer, which receives, retains and then transfers the next address code to the decoder. The counter further has a clock modulator that receives the select signal and provides first and second select signals to selectively activate the first and second transmission gates to transfer the next address code to the first and second buffers.

[0024] A first delaying circuit is optionally placed between the adder circuit and the first transmission gate to adjust timing of the transmitting of the next address code from the adder circuit to the first transmission gate. A second delaying circuit is placed between the first transmission gate and the first buffer to adjust timing of the transmitting of the next address code from the first transmission gate to the first buffer. A third delaying circuit is placed between the first buffer and the second transmission gate to adjust timing of the transmitting of the next address code from the first buffer to the second transmission gate. And, a fourth delaying circuit is placed between the second transmission gate and the second buffer to adjust timing of the transmitting of the next address code from the second transmission to the second buffer.

[0025] The counter further has an initial value circuit that places an initial value at the input of the second transmission gate. This establishes an initial value for the next address code and therefore sets a beginning count for the counter.

[0026] The adder has a first summing circuit that is to receive and add the increment signal and a least significant bit of the present address code to form a least significant bit of the next address code. A first carry circuit is connected to receive the increment signal and the least significant bit of the present address code to determine a first carry bit from the sum of the increment signal and the least significant bit of the present address code.

The adder has plurality of summing circuits, where each summing circuit is connected to receive and add one of plurality of bits of the present address code and a carry bit. The carry bit is determined from an adjacent less significant bit of the present address code to form one of a plurality of bits of the next address code. Each of a plurality carry circuits is connected to also receive one of the plurality of bits of the present address code and the carry bit determined from the adjacent less significant bit of the present address code to form one of a plurality of carry bits.

[0027] Each of the summing circuits is an exclusive-OR gate. The exclusive-OR gate has a MOS transistor of a first conductivity type and a MOS transistor of a second conductivity type. The gates of the MOS transistors are connected to a first input terminal and drains are connected to a second input terminal. First and second inverter circuits are connected such that an input of the first inverter circuit and the output of the second inverter circuit are connected to a source of the MOS transistor of the first conductivity type and an output of the first inverter circuit and the input of the second inverter circuit are connected to a source of the MOS transistor of the second conductivity type. The first and second inverter circuits are standard CMOS inverter circuits thus the exclusive-OR circuit is formed of six transistors. The output terminal of the exclusive-OR circuit is formed at the connection of the source of the MOS transistor of

the first conductivity type, the output of the first inverter circuit, and the input of the first inverter circuit.

[0028] The carry circuit is an AND circuit having a first MOS transistor of the first conductivity type. The gate of the first MOS transistor of the first conductivity type is connected to a first input terminal, the source is connected to an output terminal, and the drain is connected to a voltage reference terminal. The AND circuit has second MOS transistor of the second conductivity type with a gate connected to a second input terminal, a source connected to the output terminal, and a drain connected to a voltage reference terminal. To complete the AND circuit, a first depletion MOS transistor of the second conductivity type has its gate and source connected to the output terminal and a drain connected to a voltage supply terminal.

[0029] The clock modulator circuit has a resistor capacitor network connected to receive the increment signal and to slow the transitions of the increment signal so as to adjust a time at which the increment signal is at an active voltage level. A first buffering circuit is connected to the resistor capacitor network to generate a first select signal from the increment signal with the slowed transitions and a second buffering circuit is connected to the resistor capacitor network to generate a second select signal from the increment signal with slowed transitions. The first and second select signals are generally out of phase from each other.

[0030] A resistor, a capacitor and a depletion MOS transistor of the first conductivity type form the initial value circuit. The resistor has a first terminal connected to a voltage supply terminal. The capacitor has a first terminal connected to the second terminal of the resistor and a second terminal connected to a voltage reference terminal. The gate of the second depletion MOS transistor of the first conductivity type is connected to the connection of the first terminal of the capacitor and the second terminal of the resistor. The source is connected to the voltage supply terminal and the drain is connected to an output of the first buffer.

[0031] The method continues by selecting which of the testing evaluation devices are to be tested and then activating the first and second stimuli. The substrate is then stressed and each selected evaluation device structure is examined for failure. The hazard rate for each failure mechanism of the integrated circuit is determined and from the hazard rate the burn-in time for the integrated circuit is calculated.

Brief Description of the Drawings

[0032] Fig. 1 is a plot of the hazard rate versus time of integrated circuits of the prior art.

[0033] Fig. 2 is a diagram illustrating a semiconductor wafer highlighting integrated circuit die with kerf or scribe lines of the prior art.

[0034] Fig. 3 is a flow diagram for estimating the burn-in time for a wafer containing integrated circuit die of this invention.

[0035] Fig. 4 is a schematic diagram of a reliability testing structure of this invention.

5 [0036] Fig. 5 is a cross-sectional view of a semiconductor wafer illustrating the stacking of evaluation device structures of this invention.

[0037] Fig. 6 is a schematic diagram of the address decoder of the reliability testing structure of this invention.

[0038] Fig. 7 is a schematic diagram of the counter of the reliability structure of this invention.

10 [0039] Fig. 8a, 8b, and 8c are schematic diagrams of the exclusive-OR circuit and the AND circuit of the counter of the reliability structure of this invention.

[0040] Fig. 9a is a schematic diagram of the initial value circuit of the counter of the reliability structure of this invention.

[0041] Fig. 9b is a plot of the waveforms of the initial value circuit of Fig. 9a.

[0042] Fig. 10a is a schematic diagram of the clock modulator of the counter of the reliability structure of this invention.

[0043] Fig. 10b is a plot of the waveforms of the clock modulator of Fig. 10a.

Detailed Description of the Invention

[0044] The method of this invention utilizes test structures having common
5 Input/output pads to provide stimuli to and receive responses from
selected evaluation device structures. The results of the results of
stressing the evaluation device structures determine a hazard rate and
from the hazard rate, a burn-in time is determined. Refer now to Fig. 3 for
a detailed discussion of the method to determine burn-in of this invention.
10 A semiconductor substrate **60** of Fig. 2 is provided (Box **100**) with
integrated circuit die formed on the substrate. Testing structures of this
invention are formed (Box **105**) in the kerf or scribe line area **55** of Fig.2.
Refer now to Fig. 4 for a description of the testing structures of this
invention. Each testing structure has multiple evaluation devices **150**
15 formed in the scribe line area of the semiconductor wafer. At least one of
the multiple evaluation devices **150** is chosen by the selection circuit **145**
to be stressed to determine the hazard rate or failure rate for a chosen
failure mechanism. The evaluation devices **150** include such devices as
ring oscillator circuits, capacitor dielectric film evaluation devices, gate
20 oxide integrity devices, polycrystalline silicon heating devices, contact
metallurgy evaluation chains, interlayer via chains, MOS evaluation
devices, plasma etching antenna effect patterns, metal electromigration

structures, and input/output pad structures. An exemplary formation of the evaluation devices is shown in Fig. 5. To form gate oxide integrity devices **215**, a shallow trench isolation (STI) **205** is formed at the surface of the substrate **200**. Between each of the shallow trench isolations **205**, gate oxide regions **210** are placed on the surface of the substrate **200**. A layer of polycrystalline silicon **212** is placed on the shallow trench isolations **205** and the gate oxide regions **210**. Each gate oxide integrity device **215** is the laminations of the substrate **200**, the gate oxide regions **210**, and the polycrystalline silicon layer **212**. The gate integrity devices **215** are evaluated by placing a relatively large voltage between the polycrystalline silicon layer **212** and the substrate **200**.

[0045] Other devices are then stacked on the gate oxide integrity devices **215**. For example, via chain device **225** is formed over the gate oxide integrity devices **215**. The via chain device **225** is created by depositing a first level metal **225a** on the oxide level **220**. Multiple vias **225b** are placed to contact the first level metal **225a** and the second level metal **225c** is placed to contact each of the multiple vias **225b**. The connections are serially formed such that alternate pairs of the vias **225b** are connected by either the first level metal **225a** or the second level metal **225b** so as form a sequential chain of vias **225b**. A current is forced through the via chain device **225** and a voltage across the device is measured to determine any changes in resistivity of the vias **225c** during a stress such as temperature.

[0046] Similarly metal migration devices **235**, **240**, and **245** are formed of the first level metal **235**, the second level metal **240**, and the third level metal **245**. Again these metal migration devices are formed as part of the stack of evaluation devices to reduce the area consumed by the different evaluation devices. Additionally a contact chain device **230** is formed of a second level of polycrystalline silicon **230a**, the vias **230b**, and the second level metal **230c**. The contact metal chain device **230** evaluates the effects of the alloying of the metal of the vias **230b** into the polycrystalline silicon layers **230a**. These devices are placed in a stack with the electromigration device **245** and the gate oxide integrity device **215**.

[0047] Bonding pads **250** are formed on the gate oxide integrity devices **215**. The bonding pads are formed by layering the second polycrystalline layer **250a**, the first level metal **250a**, the second level metal **250c**, and the third level metal **250d**. The bonding pads **250** maybe used to connect to the evaluation devices or maybe used to form the input/output pad evaluation devices.

[0048] Returning to Fig. 4, the first forcing pad **155** and the first sensing pad **160** are commonly connected to the evaluation devices **150**. The first forcing pad **155** is connected externally to a device or tester to provide a stimulation signal to the selected evaluation device **150** and the sensing pad is connected to a device or tester receive a response signal from the selected evaluation test device **150**. While the first forcing pad **155** and

the first sensing pad **160** are shown connected together, the sensing pad **160** may be connected to other components of the selected evaluation device **150**.

[0049] The second forcing pad **170** and the second sensing pad **175** are connected through the MOS transmission gates **166** to the evaluation devices **150**. The second forcing pad **170** is externally connected to a device or tester to provide a second stimulus to a selected evaluation device **150** through at least one of the activated MOS transmission gates **166** and the second sensing pad receives a response from selected evaluation devices through the activated MOS transmission gates **166**. As described for the first forcing pad **155** and the first sensing pad **160**, the second forcing pad **170** and the second sensing pad **175** may be connected separately to the selected evaluation test devices **150**. However, in this instance, if the second forcing pad **170** and the second sensing pad **175** are not commonly connected, as shown, additional MOS transmission gates must be provided.

[0050] The outputs **D1**, ... , **Dn** of the address decoder **165** of the selection circuit **145** are connected to the gates of the MOS transmission gates **166** to select which of the MOS transmission gates **166** are to be connected to the second forcing pad **170** and the second sensing pad **175**. In the preferred embodiment only one of the evaluation devices **150** is selected for any given evaluation. However, it is still in keeping with the

intent of this invention that multiple evaluation devices **150** be selected simultaneously. The address inputs **A0**, ... , **Am-1** of the decoder **165** provide a binary code that is indicative of which of the MOS transmission gates **166** are activated to select the desired evaluation device **150**.

5 [0051] An example of an implementation of the address decoder **165** of the selection circuit **145** is described in Analysis and Design of Digital Integrated Circuits, second Edition, David A. Hodges & Harace G. Jackson, McGraw-Hill, New York, Chinese Edition, 1988, pp. 421 and is shown in Fig. 6. The address inputs **A0**, **A1**, and **A2** are connected to the
10 inverters **I1**, **I3**, and **I5**. The outputs of the inverters **I1**, **I3**, and **I5** are connected respectively to the inputs of the inverters **I2**, **I4**, and **I6**. The outputs of the inverters **I1**, **I3**, and **I5** are the out-of-phase version of the address inputs **A0**, **A1**, and **A2** and outputs of the inverters **I2**, **I4**, and **I6** are the in-phase version of the address inputs **A0**, **A1**, and **A2**.

15 [0052] The MOS transistors **M11**, ... , **M83** are connected serially in sets of three. For instance the MOS transistors **M11**, **M12**, **M13** are connected serially between the output terminal **D1** and the voltage reference terminal. In this example, the gate of the MOS transistor **M11** is connected to the inverter **I2**, the MOS transistor **M12** is connected to the
20 inverter **I4**, and the MOS transistor **M13** is connected to the inverter **I6**. The depletion MOS transistor **M91** is diode connected between the power supply voltage source and the output terminal **D1**. Thus when the input

address **A0**, **A1**, and **A2** are set to a first logic level (0), the MOS transistors **M11**, **M12**, **M13** are deactivated (turned off) to set the output terminal **D1** to the first logic level (1). This causes the MOS transistor **M1166a** of Fig. 4 to be turned on to effectively connect the second forcing pad **170** and the second sensing pad **175** to the evaluation device **150a**.

[0053] Each row is constructed such that the MOS transistors **M11**, ... , **M83** are configured to be activated and deactivated to select the desired row **D1**, ... , **D8**. While each address of this example shows selection of individual rows, **D1**, ... , **D8**, the circuit can be configured to activate multiple rows in any desired arrangement.

[0054] Returning to Fig. 4, the input address **A0**, **A1**, ... , **Am-1** is generated by the counter **180** incorporated in the selection circuit **145**. The control line **X** provides the increment signal for the counter **180**. The control line **X** is connected to the function control pad **185** which is connected externally to a tester or device that will transmit the increment signal to cause the counter **185** to generate a binary count, which is then decoded by the address decoder **165** to activate one of the MOS transistors **166** to select the desired evaluation device **150**. Refer now to Fig. 7 for a discussion of the structure of an embodiment of the counter **180** of the selection circuit in the testing structure of this invention. Fundamentally, the counter **180** functions by adding an incrementing bit **X** to the present input address value to form the next input address value

A0, ..., Am-1. To perform this function, the input address **A0, ..., Am-1** is connected from the second buffer **325** to the input of the adder circuit **300**. The first summing circuit **335a** of the adder circuit **300** has the least significant bit **A0** of the present input address is summed with the increment signaling bit **X** to form the least significant bit of the next input address **A0, ..., Am-1**. The first carry circuit **340a** of the adder circuit combines the least significant bit **A0** of the present input address with the increment signaling bit **X** to form the first carry bit. The remaining summing circuits **335b, ... , 335n** summed the carry bit from the lesser significant bit and the bit of the present input address **A1, ..., Am-1** to form the next input address. The remaining carry circuits **... , 340n** combine the carry bit from the lesser significant bit and the bit of the present input address **A0, ..., Am-1** to form the carry bit for the more significant bit computation.

[0055] The summing circuits **305** are exclusive-OR circuits as shown in Figs. 8a and 8b. The first input terminal **A** is connected to the gates of the P-type MOS transistor **M121** and n-type MOS transistor **M122** and the second input **B** is connected to the junction of the commonly connected drains of the MOS transistors **M121** and **122**. The source of the P-type MOS transistor **M121** is connected to the output of the inverter **I51** and the input of the inverter **I52**. The source of the N-type MOS transistor **M122** is connected to the input of the inverter **I51** and the output of the inverter **I52**.

[0056] The inverters **I51** and **I52** are as shown in Fig. 8b. The input of the inverter is connected to the gates of the P-type MOS transistor **M123** and the N-type MOS transistor **124**. The source of the P-type MOS transistor **M123** is connected to the power supply voltage source **Vcc** and the source of the N-type MOS transistor **M124** is connected to the power supply reference terminal. The output of the inverter is the junction of the connection of the drains of the MOS transistors **M123** and **M124**. The output state of the inverter being of opposite phase as the input state of the inverter.

[0057] It is easily shown that when the inputs **A** and **B** are set to the same logic level (1 or 0) that the output **C** will assume the low logic level (0). Alternately, if the inputs **A** and **B** are not equal (**A=0, B=1** or **A=1, B=0**), the output **C** is equal to the high logic level (1). This as is known in the art is the function of a summing circuit and an exclusive-OR.

[0058] Returning to Fig. 7, the carry circuits **315** are AND circuits as shown in Fig. 8c. The gates of the P-type MOS transistors **M125** and **126** are respectively connected to the input terminals **A** and **B**. The drains of the P-type MOS transistors **M125** and **126** are connected to the power supply reference terminal and the sources are commonly connected to the output terminal **C**. The depletion MOS transistor **M127** is diode connected between the power supply voltage source **Vcc** and the output terminal **C**. If the inputs **A** and **B** are both set to a high logic level (1), the output **C** has

a value of the high logic level (1). The gate of the depletion MOS transistor **M127** is connected to its own source and to the output terminal **C**. The drain of the depletion MOS transistor **M127** is connected to the power supply voltage source **Vcc**. If either or both of the inputs **A** and **B** are set to the low logic level (0), the output **C** has a value of the low logic level (0). This is, as is known in the art, provides an AND circuit as well as a carry function.

[0059] The outputs **A0'**, ... , **Am-1'** of the adder circuit **300** are optionally inputs to delaying circuits **345**. To assure the proper timing operation of the counter **180** the delaying circuits **345** provide timing delay to each of the address paths, if required. Each of the delaying circuits **345** is formed by serially connected inverters **I11**, ... , **I12**. While the illustration shows a single pair of inverters **I11** and **I12**, there may be any number of inverter **I11** and **I12** depending on the delay requirements of the counter **180**.

[0060] The outputs of the optional delaying circuits **345** or the outputs **A0'**, ... , **Am-1'** of the adder circuit **300** are the inputs to the transmission gates **310**. The transmission gates **310** control the transfer of the next input address signal from the outputs **A0'**, ... , **Am-1'** of the adder circuit **300** to the first buffer circuit **315**. The control of the transfer of the next input address from the outputs **A0'**, ... , **Am-1'** of the adder circuit **300** to the first buffer circuit is provided by the clock modulator **330**. The output **M** of

the clock modulator **330** is connected to the gate terminal of each of the transmission gates **310**.

[0061] To further control the timing of the transfer of the present address to the first buffer, a second set of delaying circuits **350** is optionally placed between the transmission gates **310**. In a manner similar to the delaying circuits **345**, each of the delaying circuits **350** is formed by serially connected inverters **I21**, ... , **I22**. While the illustration shows a single pair of inverters **I21** and **I22**, there may be any number of inverter **I21** and **I22** depending on the delay requirements of the counter **180**.

[0062] The first buffer circuit **315** is an array of static random access memory (SRAM) cells. Each cell is formed of a pair of inverter circuits **I7** and **I8** having their outputs respectively connected to their inputs to form an elementary latching circuit. When the transmission gates **310** are activated, the first buffer circuit receives and retains the next input address. The output of the first buffer circuit **315** is optionally connected to the inputs to the third delaying circuits **355** or the second set of transmission gates **320**.

[0063] The third delaying circuits **355** are optionally placed between the first buffer circuit and the second set of transmission gates **320** to provide any necessary delay to control the timing of the transfer of the present address from the first buffer circuit **315**. The third delaying circuits **355** are formed of serially connected inverters **I31** and **I32**, which are structured to

provide a certain delay. Each delaying circuit **355** may have multiple inverters to establish the required delay to cause the performance of the counter **180** to meet its requirements.

[0064] The outputs of the delaying circuits **355** or the outputs of the first buffer circuit **315** are the inputs to the transmission gates **320**. The outputs of the transmission gates **320** are either the inputs to the optional delaying circuit **360** or the second buffer circuit **325**. Control signal \overline{M} of the activation of the transmission gates **320** is provided to the gate terminal of each of the transmission gates **320** by the clock modulator **330**.

[0065] Each of the optional fourth delaying circuits **360** is formed of serially connected inverters **I41** and **I42**. As described for the other optional delaying circuits, the fourth delaying circuits delay the transfer of the present address to meet the counter timing requirements. The delay of the optional fourth delaying circuit is controlled by the structure of the inverters **I41** and **I42** and by having more than a single pair of the inverters **I41** and **I42** as illustrated.

[0066] The outputs of the optional fourth delaying circuits **360** or the transmission gates **320** are the inputs to the second buffer circuit **325**. The outputs of the second buffer circuit are the terminal connection for the input address **A0**, ..., **A_{m-1}** provided to the decoder circuit **165** of Fig. 4. The second buffer circuit is an SRAM array having SRAM cells formed by inverters **I9** and **I10**. The inverters **I9** and **I10** have their respective inputs

connected to their respective outputs to form an elementary latch circuit that retains the next input address **A0**, ... , **Am-1** at the input of the decoder circuit **165** of Fig. 4.

[0067] Since the operation of the counter **180** is based on the addition of the increment signaling bit **X** and the present input address **A0**, ... , **Am-1**, The counter must have an initial value established to insure proper sequential operation. To place the counter **180** in an initial state, the initial value circuit **335** sets the output value of the first buffer circuit **315** to have an initial value (0000 ... 00). The initial value circuit **335** consists of an initial value control circuit **336** and the P-type MOS transistors **Q1**, ... , **Qm**. Refer to Figs. 9a and 9b for a discussion of the structure and operation of the initial value function. The initial value control circuit **336** consists of a resistor **R1** and a capacitor **C1**. The first terminal of the resistor **R1** is connected to the power supply voltage source **Vcc** and the second terminal of the resistor **R1** is connected to the first terminal of the capacitor **C1**. The second terminal of the capacitor **C1** is connected to power supply reference terminal. The junction **C** of the connection of the second terminal of the resistor **R1** and the first terminal of the capacitor **C1** is connected to the gate of the P-type transistor **Qm**. The source of the P-type MOS transistor **Qm** is connected to the power supply voltage source **Vcc** and the drain of the P-type MOS transistor **Qm** is connected to an output terminal **O** that is one of the outputs of the initial value circuit. The operation of the initial value circuit **335** is shown in the plot of Fig. 9b.

When the power supply voltage source V_{cc} is activated, it rises quickly to its operational level **339**. The resistor-capacitor network formed by the resistor **R1** and the capacitor **C1** causes the voltage at the junction terminal **C** to rise slowly **338** according to the time constant of the resistor-capacitor network. While the difference in the voltage level of the power supply voltage source is greater than the threshold voltage level V_{th} of the P-type MOS transistor **Qm**, the MOS transistor **Qm** is turned on or conducting setting the voltage **339** at the drain of the P-type MOS transistor **Qm** to approximately the value of the power supply voltage source V_{cc} . When the difference in the voltage level of the voltage at the junction terminal **C** and the power supply voltage source V_{cc} is less than the threshold voltage level V_{th} of the P-type MOS transistor **Qm**, the MOS transistor begins to turn off and the voltage at the drain of the MOS transistor **Qm** is no longer influenced by the initial value control circuit **336**. This provides a high logic level (1) at the output of the first buffer **315** of Fig. 7, which is latched to the first buffer. This latched low logic level (0) is then latched to the set the output of the second buffer **325** of Fig. 7 to a low logic level (0). When the voltage level of the junction terminal **C** reaches the operating voltage level of the power supply voltage source V_{cc} , the P-type MOS transistor **Qm** turns off and the latched value of the first buffer **315** controls its output value.

[0068] Returning now to Fig. 7, when the increment signaling bit **X** is not active, the out-of-phase output \overline{M} is at the high logic level (1), thus

activating the transmission gates **320** to transfer the output of the first buffer **315** to the input of the second buffer **325**. Thus the initial value circuit initializes the output of the counter **180** to be at a low logic level (0) and the first row of the decoder circuit **165** of Fig. 4 is selected.

5 [0069] Once the initial value for the counter is set, each activation of the increment signaling bit **X** causes the clock modulator to generate the transmission gate activation control signals **M** and \overline{M} . The in-phase activation control signal **M** activates the transmission gates **310** when the increment signaling bit **X** is active and the out-of-phase activation control signal \overline{M} activates the transmission gates **320** when the increment signaling bit **X** is inactive. Thus the next count is transferred to the first buffer **315** when the increment signaling bit **X** is active and then it is transferred to the second buffer **325** when the increment signaling bit **X** is inactive. The clock modulator **330** controls the necessary timing to insure proper operation.

[0070] Refer now to Figs. 10a and 10b for a discussion of the structure and function of the clock modulator **330**. The clock modulator **330** has a resistor-capacitor network formed by the resistor **R2** and the capacitor **C2**. The first terminal of the resistor **R1** is connected to an input terminal to receive the increment signaling bit **X**. The second terminal of the resistor **R2** is connected to the first terminal of the capacitor **C2** that is designated the junction terminal **D**. The second terminal of the capacitor **C2** is

connected to the power supply reference terminal. The gates of the P-type MOS transistor **M202** and the N-type MOS transistor **M204** are connected to the junction terminal **D**. The source of the P-type MOS transistor **M202** is connected the gate and source of the N-type depletion MOS transistor **M201**. The drain of the N-type MOS transistor **M204** is connected the gate and source of the N-type depletion MOS transistor **M203**. The drains of the N-type depletion MOS transistors **M201** and **M203** are connected to the power supply voltage source **Vcc**. Further the N-type depletion MOS transistors **M201** and **M203** are diode connected to act as active loads for the MOS transistors **M202** and **M204**. The drain of the P-type MOS transistor **M202** and the source of the N-type MOS transistor **M204** are connected to the power supply reference terminal. The source of the P-type MOS transistor **M202** is the in-phase output terminal, which provides the transmission gate activation control signal **M** of the clock modulator **330** and the drain of the N-type MOS transistor **M204** is the out-of-phase terminal, which provides the transmission gate activation control signal \overline{M} .

[0071] Now examining Fig. 10b, when the increment signaling bit **X** is inactive at a low logic level (0) (between the time t_0 and the time t_1), the in-phase transmission gate activation control signals **M** is at the low logic level preventing transfer of the new next input address **A0'**, ... , **Am-1'** from being applied to the first buffer **315** of Fig. 7. The out-of-phase transmission gate activation control signal \overline{M} is at an high logic level (1) to

pass the contents (the present input address) of the first buffer **315** to the second buffer **325** of Fig. 7. At the time t_1 , the increment signaling bit **X** becomes active at a high logic level (1). The junction terminal **D** begins to increase in voltage as set by the time constant of the resistor-capacitor network (**R2** and **C2**). When the difference of voltage at the junction terminal **D** and the power supply reference terminal voltage becomes greater than the threshold voltage **V_{th}** of the N-type MOS transistor **M204**, the MOS transistor **M204** turns on and begins to conduct. The voltage of the out-of-phase transmission gate activation control signal $\overline{\text{M}}$ reaches a low logic level (0). At a time Δt after the out-of-phase transmission gate activation control signal $\overline{\text{M}}$ achieves the low logic level (0), the in-phase transmission gate activation control signal **M** rises to the high logic level (1) at the time t_2 . At the time t_1 , the adder circuit **300** of Fig. 7 generates the next input address **A0'**, ... , **Am-1'**. At the time t_2 , the transmission gates **310** are activated to transfer the next input address **A0'**, ... , **Am-1'** to the first buffer **315**.

[0072] At the time t_3 , the increment signaling bit **X** changes from the high logic level (1) to the low logic level. The voltage at the junction terminal **D** begins to decrease as dictated by the resistance-capacitance time constant of the resistor **R2** and the capacitor **C2**. When the difference between the voltage level at junction terminal **D** and the power supply voltage source becomes greater than the voltage threshold **V_{th}** of the P-type MOS transistor **M202**, the in-phase transmission gate activation

control signals **M** switches to the low logic level (0). Similarly, after the time delay caused by the resistance-capacitance time constant of the resistor **R2** and the capacitor **C2**, the voltage at the junction terminal **D** becomes less than the threshold voltage **V_{th}** of the N-type MOS transistor **M204** and the out-of-phase transmission gate activation control signal **\overline{M}** switches to the high logic level (1). At the time just after the time **t₃**, when the in-phase transmission gate activation control signal **M** reaches the low logic level (0), the transmission gates **310** are deactivated to remove any communication of the next input address **A0'**, ... , **A_{m-1}'** from the first buffer **315** of Fig. 7. At the time **t₄**, when the out-of-phase transmission gate activation control signal **\overline{M}** achieves the high logic level (1), the next address is transferred from the first buffer **315** to the second buffer **325**. The next address is then retained to apply this address to the address decoder circuit **165** of Fig. 4 and to the input of the adder circuit **300** of Fig. 7, thus completing an increment cycle.

[0073] As is apparent, the timing of the in-phase transmission gate activation control signal **M**, the out-of-phase transmission gate activation control signal **\overline{M}** , and the amount of delay of the first, second, third and fourth delaying circuits **345**, **350**, and **355** insures the proper operation of the counter circuit **180**. These timings prevent any false counts or extra counting and guarantee the proper input address being transferred to the address decoder **165** of Fig. 4

[0074] Returning now to Fig. 4, the power supply input terminal **190** is connected to an external power supply voltage source **V_{cc}**. The power supply reference terminal **195** is connected to the power supply reference or return terminal or ground. If any of the evaluation devices **150** are in fact four terminal devices, such as MOS transistors, the pads **157** and **159** are connected to the devices to augment and control the device functioning. As an example, if the evaluation device **150c** were a MOS transistor and the first forcing signal from the first forcing pad **155** and the second forcing signal from the second forcing pad **170** provided a voltage stress from the drain and source of the MOS transistor, then the gate and bulk of the MOS transistor would be connected respectively to the pads **157** and **159**. From this illustration, it is shown that number of input/output pads required for the reliability evaluation is minimized, while permitting the selection of the desired evaluation testing to generate the hazard rate of particular failure mechanisms.

[0075] Referring back now to Fig. 3 to continue discussion of the method for evaluation of the burn-in time of this invention, upon completion of the forming (Box **105**) of the test structures as described in Fig. 4 on the substrate, the substrate is placed in a chamber and subjected to an environmental stress (Box **110**) to accelerate any of the predicted failure mechanisms. At the completion of the stress (Box **110**), the evaluation devices of the test structure are examined (Box **115**) for failure. The types of failures are cataloged and a hazard rate for each failure mechanism is

determined (Box 120). The burn-in time is calculated (Box 125) from the hazard rate.

[0076] The test structures of Fig. 4 are to be included in the manufacturing of integrated circuits on substrates. The substrates are subjected to environmental stress to eliminate the infant mortality of the product as described above. The test structures are examined to create a set of statistics showing the lot-to-lot variations in the failure mechanisms and the resulting changes in the hazard rates. The test structure of Fig. 4 allows data to be collected to improve the estimates of the hazard rate and thus allow an improvement of the types of stress and the time for stressing required for burn-in.

[0077] In summary, the test structure of this invention has evaluation devices are that are stacked as they are are formed on a semiconductor substrate. There are multiple stacked evaluation devices, any of which are chosen so as to provide evaluation of certain failure mechanisms and prevent confounding of the results from other failure mechanisms. The testing structure employs a minimal number of input/output pads to insure efficient use of space on the substrate. While this testing structure maybe used in evaluation test sites for initial evaluation of the hazard rates of a new technology, it is primarily intended to be placed in the scribe line or kerf area between the integrated circuit die on the substrate. This allows

continued reliability evaluation during burn-in of the integrated circuits,
while minimizing area of the substrate consumed by test devices.

[0078] The defect density found during wafer test of the test structure of
this invention is used to estimate the duration of burn-in for the integrated
circuits. The defect density of the test structure is indicative of failure
mechanisms. Thus, by measuring the defect density (defects/cm²) within
the the testing structure of this invention during wafer testing, the burn-in
duration is calculated according to the following equation:

$$f \cong D_0 \frac{t}{50} e^{-\left(\frac{t}{10}\right)^2} \text{hrs}^{-1}$$

where:

f is the desired failure rate or hazard rate for a
particular failure mechanism.

D_0 is the defect density found within the test
structure of this invention during wafer testing.

t is the estimation of the duration of the burn-in
of the integrated circuits.

[0079] The following example demonstrates the usage of the test structure
of this invention to estimate a burn-in time for two different manufacturing
lots of a wafer of an integrated circuit. In the first lot (A), there are 2

defects found in two hundred test structures present on the wafer. Each test structure has an area of approximately 0.5 mm^2 . The defect density for lot A is calculated according to the equation:

$$D_o \cong -\frac{\ln(\text{yield})}{\text{area}} = -\frac{\ln\left(1 - \frac{2 - 0.3}{200 - 0.4}\right)}{9.5 \text{ mm}^2} = 1.7 \text{ cm}^{-2}$$

To maintain a hazard rate for the particular failure mechanism below 10^{-3} hrs^{-1} , the failure rate equation is solved to determine the burn-in time as approximately 26 hours.

[0080] In a second lot (B), the wafer testing has shown that there are two defects found in 2000 test structures. Given an identical test structure to test the failure mechanism as identified for lot A with an equal desired hazard rate, the new burn-in time for lot B is now calculated as above to be 20 hours. As can be seen from the above, lot B requires more testing at the wafer testing (2000 test structures versus 200 test structures), but allows a savings of six hours of burn-in testing (20 hours for lot B versus 26 hours for lot A). The burn-in testing of integrated circuits generally is more expensive and time consuming than the wafer testing to determine the defect density.

[0081] While this invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by

those skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the invention.

[0082] The invention claimed is: .